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# 4 History of Walkway Slip-Resistance Research at the National Bureau of Standards

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# A History of Walkway Slip-Resistance Research at the National Bureau of Standards

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A History of Walkway Slip-Resistance Research at the  
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Brian C. Pierman

ABSTRACT

This report summarizes NBS research in the area of walkway and shoe slip-resistance measurement since 1924 and outlines current activities that will provide a technical basis for slip-resistance measurement. The work of Sigler, Hunter, Boone and Brungraber represents the historic perspective. Current activities in data base development and identification of standard reference surfaces contribute to a rational basis for quantitative slip-resistance criteria for building codes and standards. Proposed future research thrusts include personal factors such as human biokinetic and perceptual variables, as well as environmental factors such as lighting in the built environment. This research will contribute to the development of new intervention strategies to reduce deaths and injuries due to slips and falls.

Key Words: Friction; measurement; reference standards; safety research;  
walkway slip-resistance.

## 1. INTRODUCTION

The National Safety Council reports that slips and falls are the major building-related cause of accidental death and injury [1].<sup>1</sup> In 1976, over 8 million falls resulted in 1.6 million disabling injuries and 14,896 deaths. The victims are primarily the young and the old, with more serious consequences for the elderly. Children under 15 (approximately 30% of the U.S. population) suffered nearly half of the disabling injuries. Adults over 65 (approximately 10% of the U.S. population) experienced 20% of the fatalities. In more than half of the falls, slippery surfaces were identified as a major contributing factor.

Existing standards and codes for walkway surfaces are generally vague and difficult to enforce since they lack quantitative definition of acceptable levels of slip-resistance.

The Center for Building Technology is advancing research to permit the inclusion of quantitative criteria for slip-resistance now missing from voluntary standards and mandatory regulations.

## 2. HISTORICAL PERSPECTIVE

The earliest work at the National Bureau of Standards (NBS) related to slips and falls focused exclusively on the measurement of coefficient of friction. Later work demonstrated a recognition of the complex array of factors which affect the risk of a slip or fall on a walkway surface.

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<sup>1</sup> Numbers in brackets refer to References.

## 2.1 R. B. Hunter

NBS has been involved in slip-resistance research for over 50 years. As early as the 1920's there was a recognized need for a quantitative safety code for walkway surfaces.

A committee of the American Standards Association<sup>1</sup> examined the problem and found that available data were inadequate. A new manufacturers' subcommittee was formed within the American Standards Association and arrangements were made to sponsor a research fellowship at NBS to investigate the frictional resistance of walkway surface materials.

The investigations carried out from 1924 to 1926 by R. B. Hunter included the development of a process for preparing (abrading to simulate wear) the specimens and a test device and procedure for measuring the coefficient of friction. Additional investigations were carried out by Hunter at NBS during 1928 to 1929. The results of all of the studies have been reported by Hunter [2].

Hunter established the following test conditions:

1. The walkway materials tested were abraded sufficiently to be representative of worn surfaces.
2. The contact area between the surfaces was comparable to the contact area between an average shoe sole and a walkway.
3. The load applied to the test sole was approximately the same as the average load to the shoe sole in walking.

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<sup>1</sup> Founded in 1918. Changed name in 1966 to the United States Standards Institute, and again in 1969 to the American National Standards Institute (ANSI).



figure 1

The Hunter Machine

4. The test apparatus gave repeatable results on the same surfaces.

Hunter described his test apparatus, illustrated in Figure 1 as follows:

"It operates on an oblique thrust principle corresponding to the thrust on the shoe in walking and consists of a right-angled frame carrying a slotted 75-pound weight between two vertical bars of the frame which serves as guides to the weight. A 10-inch thrust arm is pivoted at one end near the center of gravity of the weight and at the other end through the center of an area of a 3 by 3 inch shoe. The weight may be raised by means of the windlass, and is supported in the raised position by the friction of the shoe on the surface under test. By means of a screw and lug the shoe may be drawn forward by small increments, increasing the horizontal component of the force until the shoe slips on the surface, letting the weight drop. The lug is left in the position at which the slip occurred. The lug carries an index which shows (on a scale graduated in inches) the horizontal distance of the shoe from its position when the thrust arm is vertical."

The Hunter Machine measured dynamic rather than static friction, since the shoe was dragged across the walkway specimen until slip occurred. Hunter used rubber and leather shoe sole materials to evaluate a number of walkway surfaces, including natural and artificial stone, vitrified tile, wood, metal and various manufactured products.

Hunter found that there was no direct relationship between the coefficients of friction on clean, dry surfaces and on the same materials under various actual service conditions. For example, he found that the coefficient of friction for leather appeared to increase on wet and/or oily surfaces. For most materials, the coefficient of friction depended upon the smoothness, cleanliness, and moisture content of the two surfaces. Adaptations of his test device have been incorporated into currently used test devices such as the James Machine [3], and the newly developed NBS-Brungraber Portable Tester [4].

## 2.2 P. A. Sigler

During the 1940's and the early 1950's, an extensive program of slip-resistance research was carried out under the direction of Percy A. Sigler. The work included analysis of slow-motion photography of people walking, a study of wear patterns of shoe heels, development of a new pendulum-type tester, and electromechanical determination of the forces exerted by the foot on a walkway surface.

Sigler reviewed the previous investigations of the slip-resistance of floors and noted that measurements made of the coefficient of static friction between floor surfaces and leather soles yielded the counter-intuitive result that some smooth-faced materials had a higher coefficient of friction when wet than when dry. Sigler attributed this result to the comparatively large area of contact between the leather sole and the floor surface; a condition representative of a person standing rather than walking. In retrospect, it now seems more likely that the improved slip-resistance of wet surfaces arises from the adhesion that can be developed by a thin layer of liquid between the surfaces. The relatively long delay time between the application of the normal force and the application of the lateral force that is inherent in most slip-resistance testers can encourage the development of this adhesion.



Figure 2

The Original Model of Sigler's Pendulum Tester

Sigler approached the problem by developing a pendulum-type laboratory machine which estimated dynamic friction by indicating the energy loss of a mechanical heel sliding over a walkway surface. The Sigler laboratory machine is illustrated in Figure 2. Sigler reported "anti-slip coefficients" for samples of over 100 materials which he categorized as poor, fair and good [5]. In general, he found almost all flooring surfaces were "good" under dry conditions, and many rated "poor" under wet conditions. Table 1 describes the range of "antislip" values Sigler considered as "poor, fair and good."

Table 1. Siglers' Characterization of Antislip Values for Floor and Deck Surfaces.

Classification	Leather Heel as Sensor	Rubber Heel as Sensor
Poor	Less than 0.15	Less than 0.25
Fair	0.15 to 0.30	0.25 to 0.40
Good	More than 0.30	More than 0.40

Taken from Sigler, Percy A., Relative Slipperiness of Floor and Deck Surfaces, BMS Report 100, NBS, July 1, 1943.

Sigler recognized that the difference in slip-resistance of the same material wet and dry may represent a hazard [5]. For example, the difference in slip-resistance of wet and dry rubber heels is greater than the difference in slip-resistance of wet and dry leather heels. Hence, wet rubber heels offer more of a "surprise" to the user than wet

leather heels, even though rubber heels are generally more slip-resistant. Current NBS research, which considers factors like "surprise" is discussed in Section 4.3 of this report.

As a further fundamental study of the reasons for slips and falls, and to aid in the design of slip-resistance testers, an analysis was made of human locomotion [6]. Slow motion pictures of people walking were taken with concealed cameras in a natural setting. The films showed that when the leading foot is first placed upon the walkway, the rear foot remains in contact with the walkway, bearing part of the vertical load until the leading heel rocks forward and the foot is fully planted. A survey was also made of worn heels to determine the probable angles at which heels of shoes make initial contact with walkway surfaces. Information gained from the human locomotion studies was utilized in the design of a portable model of the pendulum tester. The portable model of the tester was used by Sigler, Geib, and Boone to test a number of floors in actual service. A careful series of tests showed the device to give repeatable results. However, adjustment of the machine settings, such as level and spring tension could appreciably change the antislip values obtained. For this reason, Sigler indicated that the antislip coefficients obtained should be considered as relative, rather than absolute values, and if incorporated into a specification or code should be based on a definite method of testing.

In a related study under Sigler's direction, an electro-mechanical force plate developed by W. E. Williams was used to give a quantitative determination of the vertical and horizontal components of the force exerted by the leg on a walkway surface during locomotion [7]. The

published data seemed to indicate that a coefficient of friction greater than 0.2 is required to prevent slippage in the forward direction and a coefficient of friction greater than 0.4 is required to prevent slippage in a backward direction. The device is illustrated in Figure 3.

### 2.3 Federal Construction Council

In 1961, NBS contributed substantially to a definitive study which established a rational framework for the development of quantitative slip-resistance standards [8]. The Federal Construction Councils' Operating Committee appointed a task group of qualified technical personnel for six Federal agencies to examine the causes and measurement of walking slipperiness.

Thomas H. Boone was the NBS participant in this group which sought to recommend performance tests to be used as a basis for establishing slip-resistant characteristics of various surfaces, with a primary focus on interior surfaces subject to pedestrian traffic.

The Task Group reviewed the literature of the field, observed demonstrations of various testing machines, and contacted flooring product manufacturers, insurance companies, trade associations, research laboratories, and others to assess the state-of-the-art of slip-resistance measurement. The Task Group reported the following conclusions and recommendations in 1961:

#### Task Group Conclusions

1. Present Status of Knowledge and Practice
  - a. Considerable research has been done.



The NBS Electro-mechanical Force Plate (1951). Used to study forces exerted by the leg on a walkway surface.

- b. Existing machines and methods are useful tools for measuring the relative slip-resistance of various materials under controlled, laboratory conditions.
- c. Available data on friction are too closely associated with the type of apparatus used and the operator's techniques to be given broad significance.
- d. A designer who has determined the slip-resistance requirements he desires in a structure has no means of translating his requirements into a meaningful specification except by selecting products which provided satisfactory performance in past experience. Similarly, maintenance personnel have no exact method of checking to ensure that the slip-resistant properties of a flooring material are preserved.
- e. Given the current state-of-the-art, it would be impracticable to attempt to establish a specific standard to ensure safety from slips.
- f. In the absence of a universally accepted criterion and method of measurement, slip-resistance claims for a particular product or material are of questionable validity.

## 2. Future Needs

- a. To develop a set of standard reference surfaces for use by designers and manufacturers and to serve as constants for calibrating and comparing all types of friction measuring equipment.
- b. To develop or select a simple, portable, economical piece of equipment which could be readily used by maintenance personnel to establish a comparative relationship between surfaces in service and a standard surface.

## Task Group Recommendations

- 1. At the present time (1961). Initiate research and development program to:
  - a. Develop a set of standard reference surfaces which are economically reproduced; usable under field or laboratory conditions, and have long-term stability/durability or are expendable.
  - b. Select or develop a simple portable device for field use in measuring slip-resistance.
  - c. Conduct a comprehensive series of tests on in-service floor surfaces thought to be hazardous and correlate the results with the standard surfaces.
  - d. Develop slip-resistance standards which consider locations and conditions of use.
- 2. In the Interim
  - a. Before installing any material which claims slip-resistant characteristics, it should be tested under conditions which simulate actual usage conditions.

- b. No single criterion should be established for all pedestrian surfaces.

### 3. In the Future

The Task Group should be reconvened after the recommended research and development is completed, with the following objectives:

- a. To classify materials intended for pedestrian traffic with respect to slip-resistance and appropriate use.
- b. To recommend the most suitable type of "antislip" materials for each type of walkway surface.
- c. To recommend maintenance procedures.

The Task Group also suggested that the recommended activities might appropriately be done by NBS.

#### 2.4 T. H. Boone.

At the time the Federal Construction Council's report was published, work was in process at NBS on the slip-resistance of walkway and roadway surfaces [9].

Thomas H. Boone, the NBS representative in the FCC study group, directed research at NBS in cooperation with the Bureau of Public Roads and ASTM Committee E-17 on Skid-resistance.

The test measurements were made with the British Portable Skid-Resistance Tester (Figure 4) developed by the Road Research Laboratory of England. This tester is identical in principle with the NBS tester developed by Sigler in 1943. The research included an evaluation of a synthetic rubber developed as a material for vehicle tires, and tests to determine the effect of 4 years of pedestrian use on samples of asphalt tile, vinyl asbestos tile, cork, linoleum and vinyl.

An attempt was also made to identify materials that could be used as standard reference surfaces. However the difficulties encountered

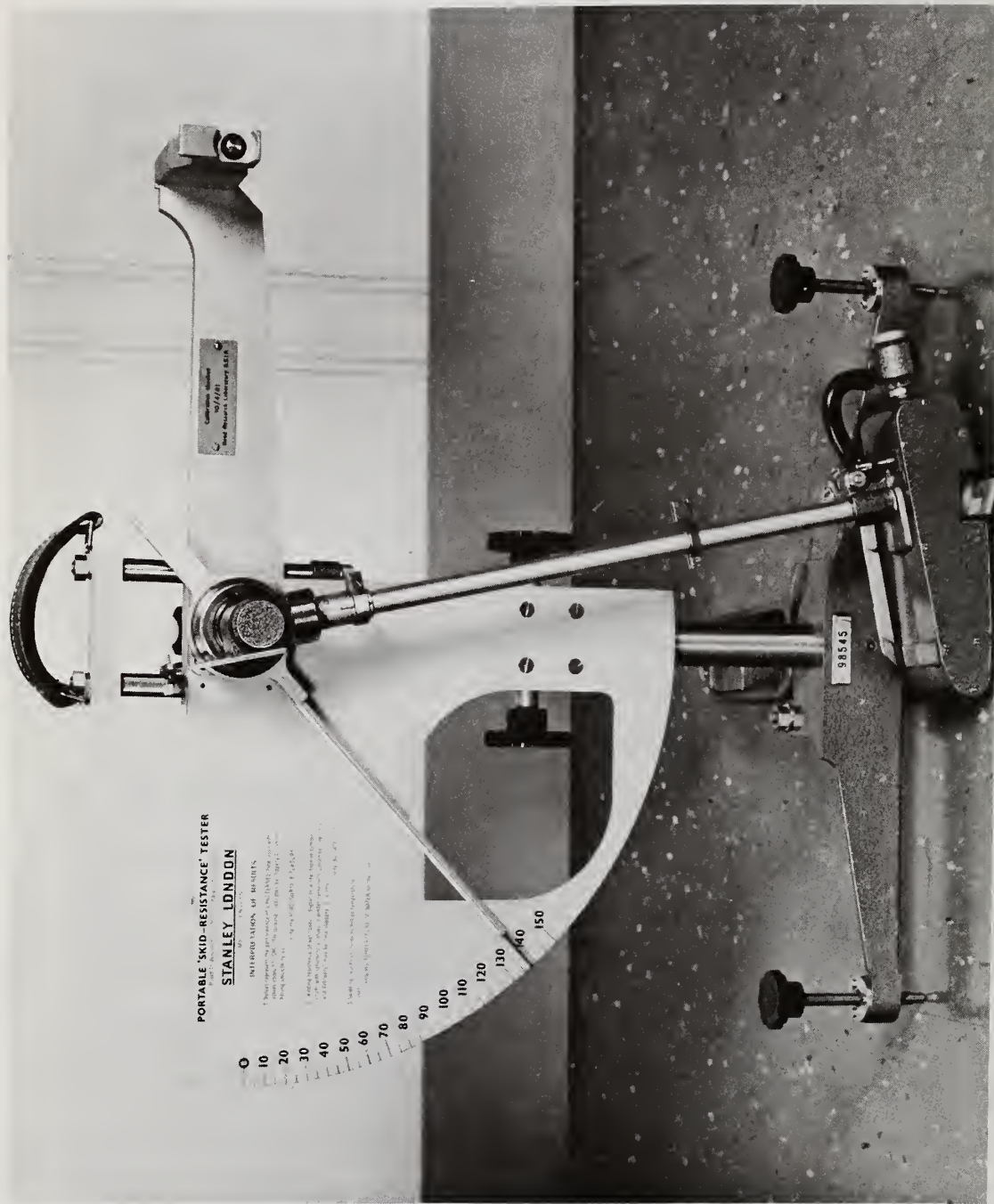


Figure 4

The British Portable "Skid-Resistance Tester". A modern day version of the Sigler Machine.

in controlling the instrument's variables precluded an exacting study. Further research on slip-resistance was not carried out at NBS until the early 1970's.

## 2.5 The Man in the Shoe

In January 1973, the Social and Engineering Sciences Group of the Technical Analysis Division of NBS produced an internal memorandum entitled "The Man in the Shoe" which outlined a research program on human walking. The goal of the proposed research was to develop requirements for shoe construction and materials which would reduce the risk of slips and falls. In addition to proposing extensive research programs on the human engineering aspects of walking, the memorandum reviewed the concept of "equivalent adherence."

A major cause of slips and falls may be an unexpected, i.e., sudden change in the adherence characteristics of the surface being walked upon. If the factor of unexpectedness could be avoided or controlled, the majority of slips and falls might be avoided. Hence, the development of a sole and heel material and tread design which offers the same slip-resistance, or "equivalent adherence" to most surfaces under most conditions could significantly reduce accidental slips and falls. While it was reported that the French have successfully developed such material for footwear used in the marine industry [10] the concept has not been extended for footwear in general. The concept of "equivalent adherence" implied that an optimum level of slip-resistance must strike a balance between slipperiness and excessive gripping.

However, a major impediment to carrying out the recommended research program was the lack of a portable, easy to use, reliable tester and a set of standard reference surfaces for calibration of test results.

### 3. RECENT NBS ACTIVITY

Recent NBS research on slip-resistance was initiated in 1974 by the Building Safety Section (BSS) of the Center for Building Technology (CBT). The mission of the Building Safety Section was to reduce building-related accidental deaths and injuries by conducting research to support the development of safety criteria, test methods and standards.

An initial analysis of accident statistics developed by the National Safety Council and the Consumer Product Safety Commission clearly identified slips and falls as the major cause of building-related accident death and injury. Hence, one of the first projects undertaken by the Building Safety Section was a preliminary study of the slipperiness of flooring.

#### 3.1 Preliminary Study of Floor Slip-Resistance

A preliminary study by Cramp and Masters involved three test methods, three flooring materials and two sensor materials under dry and wet conditions [11]. The three test methods included the James Static Friction Tester [3], the British Portable Skid Tester [12], and the Horizontal Pull Slipmeter [13], a device designed to measure static or dynamic friction. Samples of vinyl asbestos tile, vinyl tile and lineoleum were selected as representative of the three most commonly

used types of resilient flooring. The sensor materials were cowhide and styrene butadiene rubber. Table 2 is a summary of the test results.

A brief examination of the test results indicates that (a) absolute friction values are a function of the test device as well as the materials being tested, and (b) different testers are inconsistent with respect to relative ranking of materials. For example, the British Portable Tester ranked dry leather as more slip-resistant than wet leather on all three surfaces, while the Horizontal Pull Slipmeter ranked wet leather as more slip-resistant than dry leather on two surfaces and found no difference on the third surface.

### 3.2 Literature Review

From June 1974 to November 1976, Dr. Robert Brungraber of Bucknell University joined the NBS staff as a visiting scholar under the terms of the Intergovernmental Personnel Act. During this period he made significant contributions to the slip-resistance research program at NBS. One of his first tasks was to conduct an extensive review of the literature on slip-resistance and related fields [14]. The resulting document, NBS Tech Note 895, contains an annotated bibliography of over 120 relevant publications. However, Dr. Brungraber's most important contribution to this field was the development of a reliable, easily calibrated, portable slip-resistant tester.

### 3.3 NBS-Brungraber Portable Slip-Resistance Tester

Most published research on slip-resistance assumes that slip-resistance is related to coefficient of friction in a fundamental way.

Table 2. Comparison of Slip-Resistance Readings From Three Test Methods (Data from Table 17 of NBSIR 74-613, Preliminary Study of the Slipperiness of Flooring by A. Phillip Cramp and Larry W. Masters)

TEST METHOD			
Test Condition	James Static <sup>1</sup> Friction Tester	British Portable <sup>2</sup> Skid Tester	Horizontal Pull <sup>3</sup> Slipmeter
<u>VINYL ASBESTOS TILE</u>			
LEATHER/DRY	.42	36.9	.44
LEATHER/WET	.41	10.2	.66
RUBBER/DRY	---	101.4	.82
RUBBER/WET	---	24.3	.81
<u>VINYL TILE</u>			
LEATHER/DRY	.60	19.4	.60
LEATHER/WET	.35	10.4	.60
RUBBER/DRY	--	91.1	.94
RUBBER/WET	--	14.2	.96
<u>LINEOLEUM</u>			
LEATHER/DRY	.57	57.8	.64
LEATHER/WET	.45	26.3	.88
RUBBER/DRY	--	117.2	.80
RUBBER/WET	-	41.3	.87

<sup>1</sup> Tables values for the James Static Friction tester are static coefficient of friction.

<sup>2</sup> Table values for the British Portable Skid Tester are expressed in "British Portable Skid Tester Numbers," which cannot be readily converted into coefficients of friction. The values can be used to compare testers as to "relative ranking" of materials.

<sup>3</sup> Table values for the Horizontal Pull Slip Meter are coefficient of friction values derived from the "slip index" measured by the tester.

More specifically, there are considerable research data which indicate that static coefficient of friction (rather than dynamic) is the relevant variable when considering normal walking [15, 16, 17]. Owing to the serious limitations found in existing devices, Dr. Brungraber developed at NBS a new portable tester for measuring the static coefficient of walkway surfaces. The new NBS-Brungraber Tester (Figure 5) has the following characteristics:

1. It is based on the same principle of operation as the James Machine, a recognized ASTM Standard.
2. It is completely portable, and can be used under wet or dry, laboratory or field conditions.
3. It provides highly repeatable and accurate results.
4. It can be easily and reliably calibrated.
5. It accepts a wide variety of sensor materials which may be representative of bare or shod feet.
6. It is self-starting and produces a measurement immediately after being placed on a walkway surface, thereby reducing the problem of time-dependent adhesion.
7. It can be used on stairs, and on ramps inclined up to 4°.

Details of the tester development and operation are contained in NBS Tech Note 953 [4]. In 1977, R. Braun and R. Brungraber carried out an reported [18] an extensive evaluation of the theoretical basis for and empirical operation of the NBS-Brungraber tester.

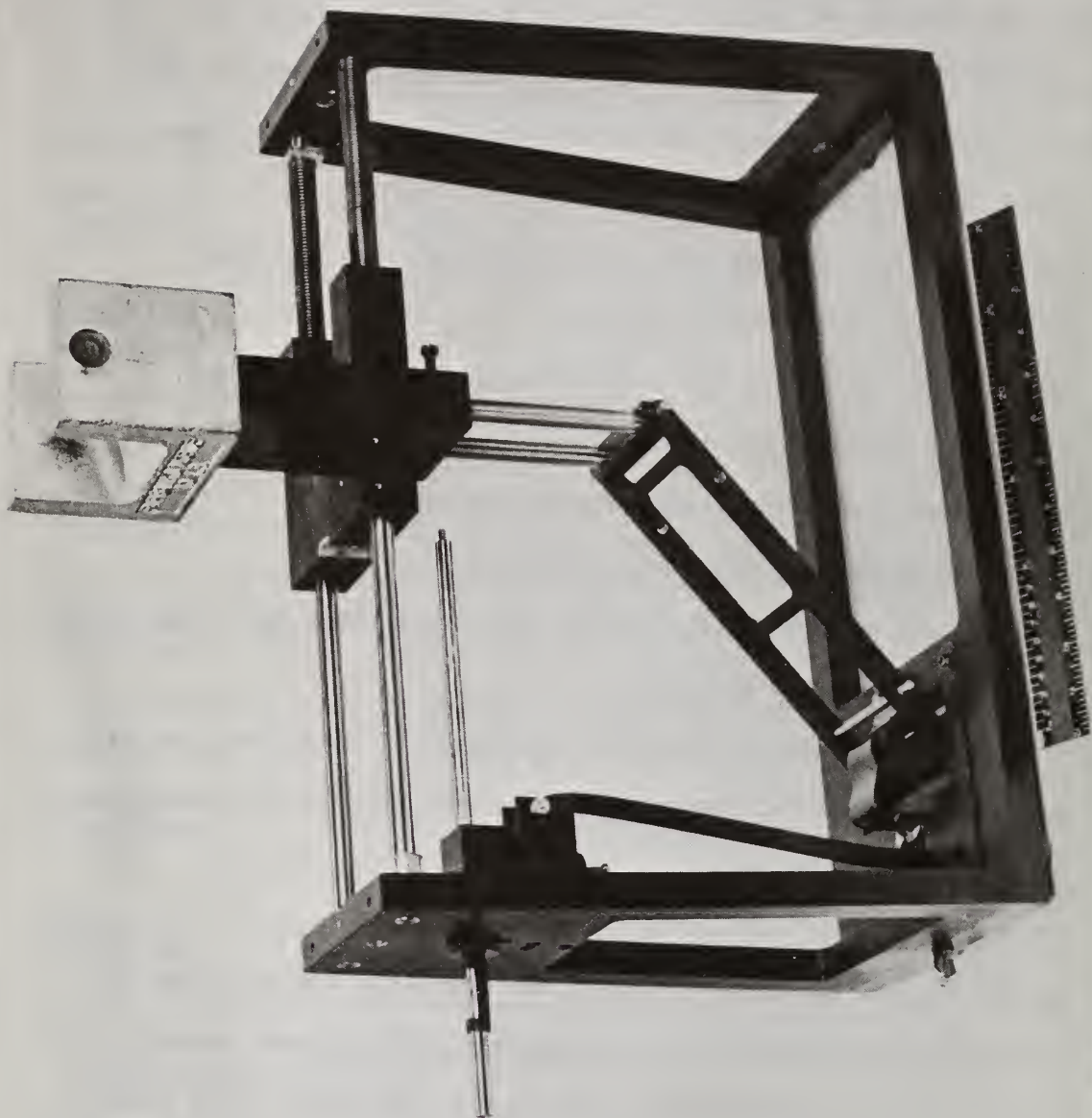


Figure 5  
NBS-Brungraber Portable Slip-Resistance Tester.

### 3.4 Problem-Oriented Research

A number of recent, narrow-in-scope research activities have been carried out for other agencies, using the NBS-Brungraber Tester and other test machines.

The Building Safety Section measured and compared the slip-resistance of five deck paints to the slip-resistance of bare concrete. A leather sensor mounted on a standard James Machine [3] was used to measure the slip-resistance of the five paints applied to both smooth and rough finished concrete under dry and wet/icy conditions. Under all test conditions, bare concrete was more slip-resistant than any of the painted specimens.

The Architectural Research Section of the Center for Building Technology, NBS, directed an extensive field study to identify characteristics of existing stairways which increase the likelihood of an accidental slip or fall. As a part of this study, the NBS-Brungraber Tester was used to collect over 3,000 measurements on 112 stairways. A comparison of the slip-resistance of stairways in general to the slip-resistance of stairways where accidents were known to have occurred led to the conclusion that slip-resistance is not a significant factor in stairway accidents [19]. This important finding may have a significant impact on stairway accident research.

In response to a petition from the National Swimming Pool Institute and the Aquaslide 'N' Dive Corp., the Consumer Product Safety Commission (CPSC) requested and subsequently funded a study by the Building Safety Section of the slip-resistance of swimming pool deck surfaces.

The objective of the study was to develop a test procedure for reference in a national safety standard for slippery surfaces around in-ground swimming pools. Preliminary results of the study indicated that the slip-resistance of pool deck surfaces could be adequately evaluated with the NBS-Brungraber Tester.

In the spring of 1975, ASTM Subcommittee F15.03.1 (Specifications and Test Methods for Slip-Resistance of Bathing Facilities) requested technical assistance from the Building Safety Section in developing a performance test for quantitatively establishing an acceptable level of slip-resistance for bathtub and shower bases. Close cooperation between the subcommittee members and the Building Safety Section staff resulted in the development of a reliable performance test which approximates the conditions that are likely to occur on a bathtub or shower surface, and adequately discriminates between currently available tub and shower materials. The test procedure uses an NBS-Brungraber Tester equipped with a silicone rubber sensor immersed in a soap solution. The work was funded by the CPSC and the proposed test procedure is currently under ASTM review [20, 21].

#### 4. NOW AND THE FUTURE

The slip-resistance work is now being conducted in the newly created Building Safety and Security Group, of the Environmental Design Research Division at the National Bureau of Standards. This group and the Construction Safety Group have assumed the tasks previously performed by the Building Safety Section.

#### 4.1 Data Base Development

An extensive series of tests of commonly encountered walking surfaces has been conducted at selected locations including Bucknell University, Lewisburg, Pennsylvania, and Gallaudet College and the National Gallery of Art, in Washington, D.C. Many of the surfaces have had long service histories with a variety of maintenance regimes. The goal of this work is to provide an understanding of the range of existing walkway conditions typically encountered in public places. Data for common floor materials including polished and worn wood, ter-razo, marble, concrete and vinyl-asbestos tile will be provided. Both wet and dry measurements have been completed and a report will be published in 1979.

#### 4.2 Standard Reference Surfaces

The Building Safety and Security Group is investigating the feasibility of utilizing standardized reference surfaces as a universal calibration system for slip-resistance testers. The objective is to develop a set of reference surfaces which are:

1. Easy to duplicate.
2. Durable (or inexpensive enough to be expendable).
3. Stable over the duration of recommended use.
4. Suitable for laboratory and field use, i.e. usable in a wet or contaminated environment.
5. Uniform and sufficiently close in coefficient of friction values to permit assessment of a tester's ability to discriminate between similar but not identical materials.

6. Sufficient in number to cover a wide range of slip-resistance values.

A universal calibration system will give researchers in different laboratories, utilizing different test devices, a meaningful way to compare interlaboratory results. Similarly, codes and standards requirements for slip-resistance could be expressed in terms of standard reference surfaces.

#### 4.3 A More General Investigation of Slips and Falls

Even for relatively slippery surfaces, slips and falls are rare events. Current NBS projects are expanding research on falls to include other variables such as related environmental factors (lighting, appearance), biomechanical considerations (gait, human structural deviations), and human perception and behavior ("surprise" concept).

Examination of these additional factors and their interactions will lead to a fuller understanding of slips and falls and identification of appropriate intervention strategies.

### 5. SUMMARY

The National Bureau of Standards has a long history of research in the measurement of walking surface friction and the causes of slips and falls on walkway surfaces. Current activities are concerned with further quantification of coefficient of friction measurements of walkway surfaces, as well as the development of a broader perspective on the nature, causes, and prevention of slips and falls. Proposed future research thrusts are related to the evaluation of personal as well as environmental factors that contribute to falls, including biomechanical,

perceptual and behavioral considerations of users and lighting and differential conditions of the environmental.

## APPENDIX

### Basic Concepts Relating to Friction and Slip-Resistance Measurement

Friction - The force which resists the relative movement of two surfaces in contact with each other.

Static Friction - The resisting force at the instant relative motion begins.

Dynamic Friction - The resisting force when movement is occurring without interruption. For most materials, dynamic friction is less than static friction.

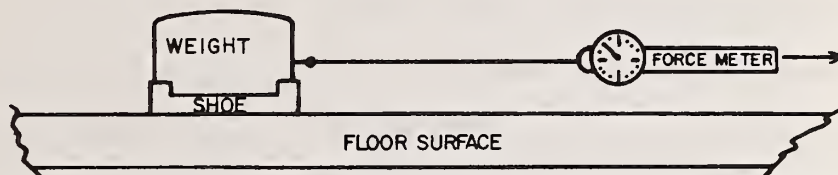
Coefficient of Friction - Defined as the ratio of the force required to move one surface over another to the total force pressing the two surfaces together.,

$$\mu = \frac{\text{HORIZONTAL FORCE}}{\text{VERTICAL FORCE}}$$

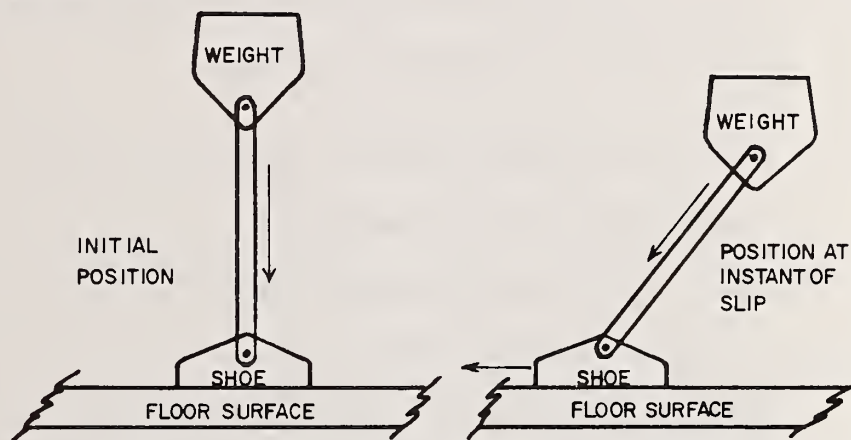
Measurement of Friction - There are two approaches to measuring friction. In the direct approach, the test device measures or indicates the horizontal and vertical forces. This includes drag-type meters and articulated strut devices. The indirect approach calculates the frictional force by observing an energy loss in the test device. The most common example of the indirect approach is a pendulum-type device. These devices are illustrated in Fig. A-1.

Drag-Type Meters - A weight of known value, faced with a shoe sole or heel material is pulled across a floor surface. The force required to

a. DRAG TYPE METER



b. ARTICULATED STRUT DEVICE



c. PENDULUM DEVICE

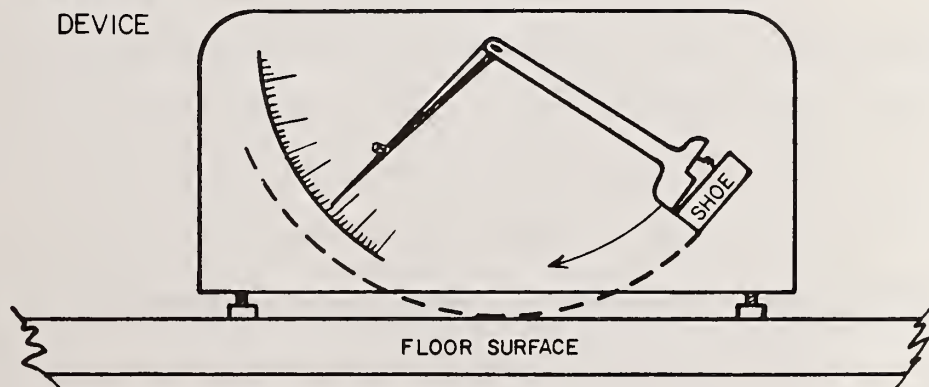


Figure A1

Typical Friction Measurement Devices

start motion (static friction) or maintain motion (dynamic friction) is recorded. (Figure A1-a)

Articulated Strut Devices - A known vertical force is applied to a shoe faced with shoe sole or heel material. An increasing lateral force is then applied until slip occurs. The ratio of lateral force at slip to the known vertical force is the coefficient of friction.

Note in Figure A1-b, there are three ways of going from the initial position to the position at the instant of slip.

- The shoe can be pushed/pulled to the left until slip occurs (dynamic friction, Hunter Machine).
- The floor surface can be moved to the left until the shoe slips (static friction, James Machine).
- The weight can move to the right until the shoe slips (static friction, NBS-Brungraber Tester).

Pendulum-type Tester - In a pendulum-type tester, a pendulum, faced with a shoe sole or heel material sweeps a path across a flooring surface. The potential energy of the pendulum at the beginning of a swing and its residual energy at the end of a swing can be determined from the known weight and position of the center of gravity of the pendulum. The difference, or loss in energy, is equal to the work done in sliding the contact material over the walkway surface, which is the average contact friction force times the distance of contact. By definition, the average frictional force is equal to the coefficient of friction times the average force normal to the plane of contact. From these relationships

an equation can be established for the coefficient of friction in which all factors except the scale reading at the end of the swing are known constants of the instrument. (Fig. A1-c)

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16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)  This report summarizes NBS research in the area of walkway and shoe slip-resistance measurement since 1924 and outlines current activities that will provide a technical basis for slip-resistance measurement. The work of Sigler, Hunter, Boone and Brungraber represents the historic perspective. Current activities in data base development and identification of standard reference surfaces contribute to a rational basis for quantitative slip-resistance criteria for building codes and standards. Proposed future research thrusts include personal factors such as human biokinetic and perceptual variables, as well as environmental factors such as lighting in the built environment. This research will contribute to the development of new intervention strategies to reduce deaths and injuries due to slips and falls.			
17. KEY WORDS (six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)  Friction; measurement; reference standards; safety research; walkway slip-resistance.			
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